Squeeze Flow Rheology of Zeolite Suspensions

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Abstract:
Aggregation, heterogeneous flows, and complex particle geometries all pose challenges in rheology. This paper uses squeeze flow rheometry techniques to examine a case, where all of these played a role. The applicability of some squeeze theories is tested, and the ability to predict results based on suspension theories is examined. The squeeze flow data is shown to deviate from Stefan's Law [1]. The suspension rheology deviated from predicted theory, but by taking into account particle effects such as aggregation the fit to the empirical Maron-Pierce equation [2] could be understood. The conclusions of this study show how using only squeeze flow techniques the synergistic nature of these effects can be better understood.

Zusammenfassung:
Aggregation, heterogenes Fließen und komplexe Partikelgeometrien stellen alle Herausforderungen in der Rheologie dar. In diesem Beitrag werden quetschrheometrische Verfahren zur Untersuchung von Suspensionen angewandt. Es wird die Anwendbarkeit einiger Drucktheorien getestet und die Fähigkeit, Ergebnisse auf Basis von Suspensionstheorien vorherzusagen, wird untersucht. Es wird gezeigt, dass die Druckflussdaten vom Stefanschen Gesetz [1] abweichen. Die Suspensionsrheologie wich von der vorhergesagten Theorie ab, doch durch Berücksichtigung von Partikelwechselwirkungen wie etwa Aggregation konnte verstanden werden, wie sie zur empirischen Maron-Pierce-Gleichung [2] passt. Die Schlussfolgerung aus dieser Studie ist, dass die synergetischen Eigenschaften dieser Effekte bei alleiniger Benutzung von Druckflusstechniken besser verstanden werden kann.

Résumé:
L'agrégation, les flux hétérogènes et les géométries de particules complexes constituent tous des défis en termes de rhéologie. Cet article utilise les techniques de la rhéométrie des flux de pression afin d'étudier un cas, dans lequel tous ces effets jouent un rôle. L'applicabilité de certaines théories de la pression est testée et la capacité à prévoir les résultats en fonction des théories de la suspension est examinée. Il a été prouvé que les données des flux de pression déviaient de la loi de Stefan [1]. La rhéologie de la suspension s'écartait de la théorie prédite, mais en prenant en compte les effets des particules, tels que l'agrégation, la correspondance à l'équation [2] empirique Maron-Pierce a pu être comprise. Les conclusions de cette étude montrent comment en utilisant uniquement des techniques de flux de pression, on peut mieux comprendre la nature synergique ce ces effets.

Key words: zeolites, suspensions, squeeze flow, compression, relative viscosity, heterogeneous flow

1 INTRODUCTION

Squeeze flows are found in industrial, automotive, food, biological, and engineering domains. Squeeze flow rheometry is often used as a straightforward tool to determine the flow properties of highly viscous liquids [3]. When examining lower viscosity solutions and suspensions where particle-particle interactions can become more pronounced the technique becomes more complicated. Published reports on the squeezing flow of highly concentrated suspensions show that as the concentration of a suspension gets very large, heterogeneities come into the flow profile and cause fluid behavior that is incongruous with most models. This study evolved from the need to explain and predict electrorheological squeeze flow for zeolite suspensions [4].

The rheology of suspensions of particles may differ from that of pure Newtonian liquids in at least three ways. First in suspensions it is possible to reach a concentration of the suspended (solid) phase that is so high that heterogeneous flow occurs. Heterogeneous flow is flow where more than one phase is present; in the case of a concentrated suspension the suspended phase would form aggregates of solid phase in the dispersion. Already mentioned above this case has yet to be dealt with quantitatively,

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tionship derived by Kitano and Kitaoka using the Maron-Pierce equation [20] has been shown to be one of the most broad useable relationships covering several different effects in suspensions [21, 22].

Einstein's correlation for a suspension of noninteracting hard spheres is given in Figure 8. In the figure it only matches at the lowest concentration and this agrees with other suggestions that his equation is only useful at very small volume fractions. The empirical equation requires an empirical constant *A*. For *A* = 0.68 which corresponds to spherical particles it gives a slight improvement above Einstein's equation. The equation does not agree with the expression because zeolites as shown in Figure 9 are not represented well by spheres in solution. When the empirical constant is set to 0.44 the curve agrees with the data at the highest concentration using constant area. This suggests not only that the suspension is better matched by a rough crystal then by the non interacting spheres, but further validates the relative viscosity calculations for squeeze flow.

The low viscosity sample is shown in Figure 10. This figure demonstrates that similar to the high viscosity suspension the spherical models do not work. However, the rough crystal model matches only at low values, but at higher values the relative viscosity values are much greater. This is due again to particle-particle interactions creating a larger overall force. Even the high aspect ratio of 18 does not account for the increases in relative viscosity. Previously it has been experimentally demonstrated that in suspensions of aggregates as the irregularity increases the packing volume parameter which could be correlated to *A* also changes [22]. For the porous zeolites this means both their porosity and aggregation effects play significant role. At all concentration the irregular shape and porosity of the particles is significant. However, as aggregation occurs at higher concentrations the increasing of particle-particle effects change the parameters as was shown for the rheology of the suspension as well.

5 CONCLUSION

From the results of the zeolite suspension squeeze flow investigation, it can be concluded that suspension concentration has at least two effects on the squeezing force. The suspension concentration increases the suspension viscosity in squeeze flow resulting in an increase in the squeeze force. Also the increasing of the suspension concentration increases the likelihood that phase separation will occur, and in the case of the zeolites studied that phase separation will result in particle-particle interactions that create a greater squeezing force for lower viscosity fluids, but a decrease in the squeezing force for high viscosity fluids.

The investigation reveals also the effects of the carrier fluid viscosity on the sample. The effect that the oil has on dependence of the concentration on the squeezing force in this test showed that this effect increased with increasing concentration. At low concentrations the suspension for high and low viscosity oils were very close to the same relative viscosities, but as the concentration increased the effect that the concentration had on viscosity for both oils diverged. The higher viscosity oils minimize particle-particle interactions for the zeolites in the suspension. The lower viscosity oils produced suspensions more prone to particle-structural effects.

Finally the investigation revealed that both effects of viscosity and concentration in a suspension for squeeze flow need to be examined not just in isolation, but synergistically. This is not just because of phase separation, but due to the nature of squeeze flow, which is transient and is strongly affected by small changes in the bulk of the material.

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